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(54) Title: APPARATUS AND METHOD FOR DETERMINING SPATIAL ORIENTATION
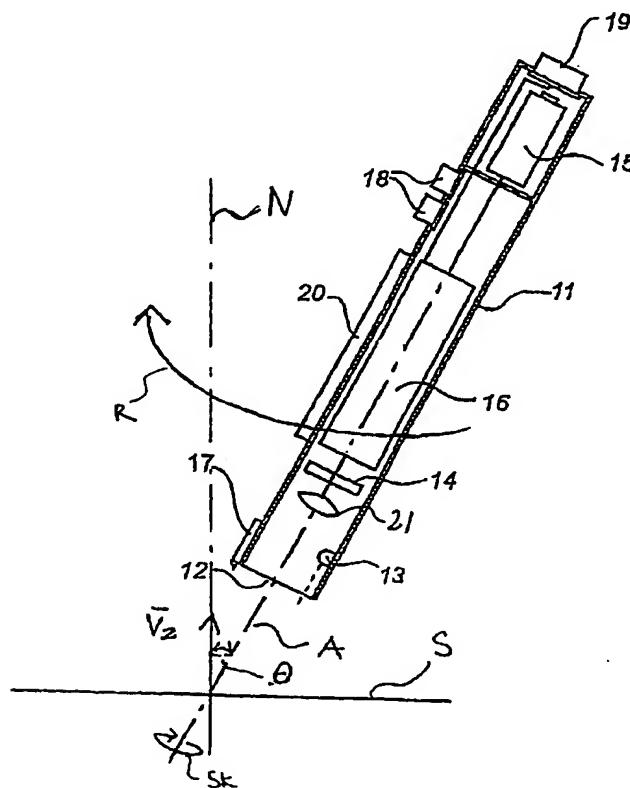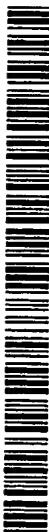
(57) Abstract: An apparatus and a corresponding method for determining a spatial relationship between a surface provided with a predetermined pattern and the apparatus are disclosed. A part of the surface is imaged in the apparatus, after which the image is compared with the predetermined pattern. The comparison produces at least one reference measurement, by means of which it is possible to determine the spatial relationship expressed in at least the parameters which define the orientation of the surface. By using knowledge of the predetermined pattern together with an algebraic model of the image formation by the apparatus, a numerical adaptation can be carried out. Parameters obtained from the adaptation can then be used to calculate the spatial relationship between the apparatus and the surface in terms of, for example, a distance between the apparatus and the surface or an angle between the surface and an axis extending through the apparatus.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

APPARATUS AND METHOD FOR DETERMINING SPATIAL

ORIENTATION

TECHNICAL FIELD

The present invention relates to methods and apparatuses
for determining the spatial relationship of an input
apparatus to a surface.

BACKGROUND

5   For the input of information into computerized equipment,
use is made in many applications of, for example, a
pointing device, often referred to as a computer mouse,
or digitizing pens. A feature common to input devices of
these types is that in most cases they supply only
10   information which can be directly related to two spatial
dimensions.

A typical computer mouse is moved on top of a plane
surface, and coded information about the movement of the
mouse on the surface is supplied to a computer via mecha-
15   nical rolling arrangements, electromechanical circuits
and coding logic.

A digitizing pen can be designed with an optical or
electric sensor in its tip, and contact with a digitiz-
ing tablet designed for the purpose generates signals,
20   analog or digital, which can be interpreted in a computer
in terms of the contact position of the pen tip on the
tablet.

In some applications, it is also desirable to obtain
information from a pointing device or a digitizing pen

2

about, for example, its inclination or, more generally,
its position in relation to the surface with which it is
in contact or to which it is near.

According to the known art, this has often been achieved
5   by means of relatively complicated electrical
arrangements in the pointing device and a base intended
specifically for the pointing device. An example of
this known art can be seen in US Patent Specification
5,198,623 which discloses a method in a digitizing
10   arrangement for establishing the tilting angle of a pen
forming part of the arrangement. The pen has a coil
which, in interaction with an array of electrical con-
ductors in a digitizing tablet, generates electrical
pulses. The electrical pulses are analyzed with regard to
15   pulse form, a measurement thus being obtained of the tilt
of the pen in relation to the surface of the tablet.

The arrangements and the method disclosed in US 5,198,623
comprise a great many electrical components, which can be
seen as a disadvantage when simple and inexpensive
20   solutions are being sought.

It can also be seen as a disadvantage that it is
necessary for the pen to interact with a special digitiz-
ing tablet. A user is therefore tied to a specific combi-
nation of pen and base.

25   A method and an apparatus for recording data from a sheet
is disclosed in US 5,101,096. Data in the form of optical
recording dots arranged in perpendicular lines and
columns are detected by a two dimensional (CCD) optical
line sensor. An inclination angle is calculated between
30   the optical recording lines and the optical line sensor.
The inclination angle is then used to restore the
detected data.

However, the method and arrangement disclosed in US
5,101,096 is only directed to solve a problem of
compensating for a misalignment between the optical
recordings arranged in straight lines and the CCD-
5   detector elements that are arranged in similar lines and
columns. US 5,101,096 hence fails to show how to
calculate any misalignment due to the lines of the
recordings and the detector not being parallel.

A generally emphasized problem related to the previously
10   known art is therefore how a more general determination
of spatial relationship between, for example, a
digitizing pen and a patterned surface is to be made
possible in a flexible and simple manner.

SUMMARY OF THE INVENTION

15   One object of the present invention is therefore to solve
problems related to the previously known art. This is
achieved by means of apparatuses according to claims 1
and 15 below, and methods and computer programs according
to claims 29, 41, 42 and 54 as well as a use according to
20   claim 55.

According to a first aspect of the invention, an
apparatus and a corresponding method for determining a
three-dimensional spatial relationship between a surface
provided with a predetermined pattern and the apparatus
25   are disclosed. A part of the surface is imaged in the
apparatus, after which the image is compared with the
predetermined pattern. The comparison produces at least
one reference measurement, by means of which it is
possible to determine the spatial relationship expressed
30   in at least the parameters which define the orientation
of the surface. By using knowledge of the predetermined
pattern together with an algebraic model of the image

4

formation by the apparatus, a numerical adaptation can be carried out. Parameters obtained from the adaptation can then be used to calculate the spatial relationship between the apparatus and the surface in terms of, for

5   example, a distance between the apparatus and the surface or an angle between the surface and an axis extending through the apparatus. In a preferred embodiment, said adaptation will be discussed in detail when a surface with a dot pattern is used.

10   One effect of the invention is therefore that, by comparing a predetermined pattern with an image of the pattern, an assessment of, for example, the rotation, tilt and skew of the apparatus as well as the distance between the apparatus and the patterned surface can be

15   obtained. As is known in the art, the orientation of a device such as a pen with respect to the pattern on the surface can be expressed using three numbers: rotation, tilt and skew. The skew is defined as the angle of rotation of the pen around its rotational axis. The tilt

20   angle is the angle the pen extends with respect to a normal vector to the surface and the rotation is the angle of rotation of the pen with respect to the normal vector. A zero tilt implies that the rotation is equal to the skew.

25   One advantage of an apparatus and a corresponding method as above is of course that no complicated electrical arrangement is required, as is the case in the known art. Only processing means, which are suitably programmed by software, are required in order to obtain the desired

30   measurement of the spatial positional relationship between the apparatus and the surface.

5

According to a second aspect of the present invention, an apparatus and a method for position determination are disclosed. An image is produced of one partial surface of a number of partial surfaces on a surface which is

5   provided with a position-coding pattern. Image-processing is carried out with regard to this image, which comprises locating a predetermined plurality of symbols in the image and determining the value of each of these predetermined symbols. The symbols comprise a raster

10   point and at least one marking, the raster point forming part of a raster which extends over the surface, and the value of each symbol being indicated by the position of said marking in relation to a raster point.

The position-coding pattern which has been imaged is

15   separated into a first position code for a first coordi-nate for the partial surface and a second position code for a second coordinate for the partial surface. The first coordinate is then calculated by means of the first position code, and the second coordinate is calculated by

20   means of the second position code. A third coordinate is calculated by comparing the imaged part of the pattern with the predetermined pattern, at least one reference measurement being obtained, which depends on the orientation of the surface. Reference measurements

25   determine the spatial relationship expressed in at least the parameters which define the orientation of the sur-face. This spatial relationship then determines the third coordinate.

The first two coordinates are thus obtained by

30   interpreting the symbols, where displacements of the markings forming part of the symbols in relation to a normal position contain information in the form of the

6

two-dimensional positions on the surface read. The third
coordinate is calculated by means of the information
obtained from the distortion of the known pattern which
occurs on image formation by the apparatus, the image
5   formed being for the most part affected by the relative
spatial positional relationship between the reading appa-
ratus and the patterned surface. For example, the pat-
tern in the image formed is distorted in perspective when
reading is carried out in a direction which does not lie
10   in the normal direction in relation to the surface. More-
over, the imaged pattern is changed in terms of scale
when reading is carried out with the apparatus located at
a greater distance from the surface.

In a corresponding manner to that in the first aspect
15   described above, a reference measurement can be used in
order to calculate the three-dimensional spatial
relationship between the apparatus and the surface. With
this, it is possible to determine, for example, a
distance between the apparatus and the surface or an
20   angle between the surface and an axis extending through
the apparatus. These measurements can then be used in a
mathematically simple manner for determining the third
coordinate.

According to this aspect of the invention, a pointing
25   device can therefore be produced which can supply
coordinates which represent three dimensions to, for
example, a computer. The application in the computer
using the three-dimensional positional information,
including rotation, tilt and skew can of course be of
30   different types. Particularly interesting are appli-
cations relating to calligraphy. Calligraphy applications
include those applications of drawing/writing where the

device is used as a brush. In these applications the
rotation, tilt and skew of the device, as determined in
accordance with the invention, may be used to represent,
on a display or when printing, a digitized trail made

5   with the device. If combined with an assumed or selected
shape of a virtual brush, such a trail will on screen or
in print, have the characteristics of a trail made
manually by a person using a brush, i.e. a trail with
varying widths. It is also possible to utilize, e.g., the

10   information regarding the distance between the pen and
the surface, as determined by the invention, to represent
a color density of the trail when presenting it on a
screen or on paper, thus further enhancing the likeness
with a manually painted trail.

15   Moreover, general applications relating to biometrics,
i.e. measuring of the movement of, e.g., a hand which
holds and moves the device. Such an application is
signature recognition.

Advantages of the invention include the fact that it can

20   be implemented in an apparatus without moving parts and
does not require the use of complicated, expensive bases
in the form of digitizing tablets full of electronics. An
apparatus according to the invention is preferably
produced using optical components and an image-processing

25   processor which reads a pattern on, for example, a sheet
of paper, the complexity of which in terms of physical
construction is, to say the least, reduced in comparison
with a digitizing tablet according to the known art.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 shows schematically an embodiment of a product

30   provided with a position-coding pattern,

8

Figs 2a-2d show schematically how the symbols can
be designed in an embodiment of the invention,

Fig. 3 shows schematically an example of 4x4 symbols used
to code a position,

5   Fig. 4 shows schematically an apparatus according to the
present invention, which can be used for position
determination in three dimensions,

Fig. 5 shows schematically how a pattern on a surface is
imaged in an apparatus according to the invention, and

10   Fig. 6 shows how a pattern is distorted in an image
formed in an apparatus according to the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

For the sake of clarity, the detailed description below
of the invention has been divided into a number of part
descriptions. By way of introduction, a coding pattern

15   will be described with reference to Figs 1, 2a-d and 3.
As outlined above, this coding pattern can represent
positional information but can also represent other
information. After the description of the coding pattern,
an apparatus intended to read the pattern will then be

20   described with reference to Fig. 4. The way a pattern can
be used for calculating spatial orientation of an appara-
tus reading the pattern will then be described with refe-
rence to Figs 5 and 6.

Although only one example of a coding pattern will be

25   used in illustrating the invention, it is possible to
make use of any other suitable coding pattern. Examples
of such patterns are to be found in US-A-5,852,434
(Sekendur), US-A-5,051,736 (IBM), EP-A-0 469 864 (Xerox)
as well as our own disclosure WO 00/73983, which is

30   hereby included by reference. Moreover, the coding

9

pattern used below is described in some more detail in our own disclosures PCT/SE00/01895, PCT/SE00/01897 and WO 01/16691 hereby also included by reference.

Fig. 1 shows a part of a product in the form of a sheet
5   of paper 1 which, on its surface 2, is provided with an optically readable position-coding pattern 3 enabling position determination. The position-coding pattern consists of symbols 4 which are arranged systematically across the surface 2 so as to make its appearance
10   "patterned". The sheet of paper has an x-coordinate axis and a y-coordinate axis. In this case, position determination can be carried out on the entire surface of the product. In other cases, the surface allowing position determination may constitute a smaller part of the pro-
15   duct. The sheet of paper can be used, for example, to produce an electronic representation of information which is written or drawn on the surface. The electronic representation can be produced by continuously determining, while writing on the surface with a pen, the position of
20   the pen on the sheet of paper by reading the position-coding pattern.

The position-coding pattern comprises a virtual raster which therefore neither is visible to the human eye nor can be detected directly by an apparatus which is to
25   determine positions on the surface, and a plurality of symbols 4 which are each capable of assuming one of four values "1"-"4" as will be described below. It should be pointed out here that, for the sake of clarity, the position-coding pattern in Fig. 1 has been greatly
30   enlarged. Furthermore, the position-coding pattern is shown on only part of the sheet of paper.

10

The position-coding pattern is arranged in such a manner
that the position of a partial surface on the writing
surface is coded by the symbols on this partial surface.
A first and a second partial surface 5a, 5b are indicated

5   by dashed lines in Fig. 1. That part of the position-
coding pattern (in this case 3x3 symbols) which is
present on the first partial surface 5a codes a first
position, and that part of the position-coding pattern
which is present on the second partial surface 5b codes a

10   second position. The position-coding pattern is therefore
partly common to the adjoining first and second
positions. Such a position-coding pattern is referred to
in this application as "floating".

Figs 2a-d show an embodiment of a symbol which can be

15   used in the position-coding pattern according to the
invention. The symbol comprises a virtual raster point
6 which is represented by the intersection between the
raster lines, and a marking 7 which is in the form of a
dot. The value of the symbol depends on where the marking

20   is located. In the example in Fig. 2, there are four pos-
sible positions, one on each of the raster lines extend-
ing from the raster points. The displacement from the
raster point is equal for all the values. In the follow-
ing, the symbol has the value 1 in Fig. 2a, the value 2

25   in Fig. 2b, the value 3 in Fig. 2c and the value 4 in
Fig. 2d. In other words, there are four different types
of symbol.

Each symbol can thus represent four values "1-4". This
means that the position-coding pattern can be divided

30   into a first position code for the x-coordinate, and a
second position code for the y-coordinate. The division
is effected as follows:

Symbol value	x-code	y-code
1	1	1
2	0	1
3	1	0
4	0	0

The value of each symbol is therefore translated into a
first digit, in this case bit, for the x-code and a
5   second digit, in this case bit, for the y-code. In this
manner, two completely independent bit patterns are
obtained. The patterns can be combined to form a common
pattern which is coded graphically by means of a plura-
lity of symbols according to Fig. 2.

10 Each position is coded by means of a plurality of
symbols. In this example, use is made of 4x4 symbols
to code a position in two dimensions, that is to say an
x-coordinate and a y-coordinate.

The position code consists of a number series of ones and
15 zeros which have the characteristic that no sequence of
four bits appears more than once in the series. The
number series is cyclic, which means that
the characteristic also applies when the end of the
series is connected to its beginning. Thus a four-bit
20 sequence always has an unambiguously determined position
in the number series.

The series can be at most 16 bits long if it is to have
the characteristic described above for sequences of four
bits. In this example, however, use is made of a series
25 having a length of only seven bits as follows:

12
"0 0 0 1 0 1 0".

This series contains seven unique sequences of four bits
which code a position in the series as follows:

Position in the series	Sequence
0	0001
1	0010
2	0101
3	1010
4	0100
5	1000
6	0000

5

For coding the x-coordinate, the number series is written
sequentially in columns across the entire surface that is
to be coded. The coding is based on the difference or
positional displacement between numbers in adjacent
10   columns. The size of the difference is determined by the
position (that is to say the sequence) in the number
series, with which the column is made to begin. More spe-
cifically, taking the difference modulo seven between,
on the one hand, a number which is coded by a four-bit
15   sequence in a first column and which can thus have the
value (position) 0-6, and, on the other hand, a corre-
sponding number (that is to say the sequence on the same
"level") in an adjacent column, the result will be the
same irrespective of where along the two columns the com-
20   parison is made. By means of the difference between two

13

columns, it is therefore possible to code an x-coordinate
which is constant for all y-coordinates.

Since each position on the surface is coded with
4x4 symbols in this example, three differences (having
5   the value 0-6) as stated above are available to code the
x-coordinate. The coding is then carried out in such a
manner that, of the three differences, one will always
have the value 1 or 2 and the other two will have values
in the range 3-6. Consequently, no differences are allow-
10   ed to be zero in the x-code. In other words the x-code
is structured so that the differences will be as follows:

(3-6) (3-6) (1-2) (3-6) (3-6) (1-2) (3-6) (3-6) (1-2)...

Each x-coordinate is therefore coded with two numbers
between 3 and 6 and a subsequent number which is 1 or 2.
15   If three is subtracted from the high numbers and one from
the low, a number in mixed base will be obtained, which
directly yields a position in the x-direction, from which
the x-coordinate can then be determined directly, as
shown in the example below.

20   By means of the principle described above, it is thus
possible to code x-coordinates 0,1,2 etc. by means of
numbers representing three differences. These differences
are coded with a bit pattern which is based on the number
series above. The bit pattern can finally be coded
25   graphically by means of the symbols in Fig. 2.

In many cases, when reading 4x4 symbols, a complete
number which codes the x-coordinate will not be produc-
ed, but parts of two numbers. Since the least significant
part of the numbers is always 1 or 2, however, a complete
30   number can easily be reconstructed.

14

The y-coordinates are coded according to the same
principle as is used for the x-coordinates. The cyclic
number series is repeatedly written in horizontal rows
across the surface which is to be position-coded. In
5   exactly the same way as for the x-coordinates, the rows
are made to begin in different positions, that is to say
with different sequences, in the number series. However,
for the y-coordinates, use is not made of differences,
but coordinates are coded with numbers that are based on
10   the starting position of the number series on each row.
This is because, when the x-coordinate for 4x4 symbols
has been determined, it is possible to determine the
starting positions in the number series for the rows that
are included in the y-code in the 4x4 symbols. In the
15   y-code, the most significant digit is determined by let-
ting this be the only one that has a value in a specific
range. In this example, one row of four is made to begin
in the position 0-1 in the number series to indicate that
this row relates to the least significant digit in a
20   y-coordinate, and the other three are made to begin in
the position 2-6. In the y-direction, there is thus a
series of numbers as follows:

(2-6) (2-6) (2-6) (0-1) (2-6) (2-6) (2-6) (0-1) (2-6)...

Each y-coordinate is thus coded with three numbers
25   between 2 and 6 and a subsequent number between 0 and 1.

If 0 is subtracted from the low number and 2 from the
high numbers, a position in the y-direction in mixed
base, from which it is possible to determine the y-coor-
dinate directly, is obtained in the same manner as for
30   the x-direction.

With the above method, it is possible to code
4 x 4 x 2 = 32 positions in the x-direction. Each such

15

position corresponds to three differences, which gives
3 x 32 = 96 positions. Moreover, it is possible to code
5 x 5 x 5 x 2 = 250 positions in the y-direction.
Each such position corresponds to 4 rows, which gives

5   4 x 250 = 1000 positions. Altogether it is thus possible
to code 96000 positions. Since the x-coding is based on
differences, however, it is possible to select the posi-
tion in which the first number series begins. Taking
account of the fact that this first number series can

10   begin in seven different positions, it is possible to
code 7 x 96000 = 672000 positions. The starting position
of the first number series in the first column can be
calculated when the x-coordinate has been determined.
The above-mentioned seven different starting positions

15   for the first series may code different sheets of paper
or writing surfaces on a product.

With a view to further illustrating the invention
according to this embodiment, a specific example follows,
which is based on the described embodiment of the posi-

20   tion code.

Fig. 3 shows an example of an image with 4x4 symbols
which are read by an apparatus for position determina-
tion.

These 4x4 symbols have the following values:

25   4 4 4 2

3 2 3 4

4 4 2 4

1 3 2 4

These values represent the following binary x- and

30   y-codes:

16

x-code:	y-code:
0 0 0 0	0 0 0 1
1 0 1 0	0 1 0 0
0 0 0 0	0 0 1 0
1 1 0 0	1 0 1 0

5

The vertical x-sequences code the following positions in
the number series: 2 0 4 6. The differences between the
columns will be -2 4 2, which modulo 7 gives: 5 4 2,
which in mixed base codes the position (5-3) x 8 + (4-3)
10   x 2 + (2-1) = 16 + 2 + 1 = 19. Since the first coded
x-position is position 0, the difference which is in the
range 1-2 and which can be seen in the 4x4 symbols is the
twentieth such difference. Since, furthermore, there is a
total of three columns for each such difference and there
15   is a starting column, the vertical sequence furthest to
the right in the 4x4 x-code belongs to the 61st column in
the x-code (3 x 20 + 1 = 61) and the one furthest to the
left belongs to the 58th.

The horizontal y-sequences code the positions 0 4 1 3 in
20   the number series. Since these series begin in the 58th
column, the starting position of the rows is these
numbers minus 57 modulo 7, which yields the starting
positions 6 3 0 2. Translated into digits in the mixed
base, this will be 6-2, 3-2, 0-0, 2-2 = 4 1 0 0, where
25   the third digit is the least significant digit in the
number in question. The fourth digit is then the most
significant digit in the next number. In this case, it
must be the same as in the number in question. (The
exception is when the number in question consists of
30   the highest possible digits in all positions. It is

then known that the beginning of the next number is one greater than the beginning of the number in question.)

The position of the four-digit number will then be $0x50 + 4x10 + 1x2 + 0x1 = 42$ in the mixed base.

5   The third row in the y-code is thus the 43rd which has the starting position 0 or 1, and, since there are four rows in all on each such row, the third row is number $43x4=172$.

In this example, the position of the uppermost left
10 corner for the 4x4 symbol group is thus (58,170).

Since the x-sequences in the 4x4 group begin on row 170, the x-columns of the entire pattern begin in the positions of the number series $((2\ 0\ 4\ 6)\ -169)$ modulo $7 = 1\ 6\ 3\ 5$. Between the last starting position (5) and
15 the first starting position, the numbers 0-19 are coded in the mixed base, and, by adding up the representations of the numbers 0-19 in the mixed base, the total difference between these columns is obtained. A primitive algorithm for carrying this out is to generate these
20 twenty numbers and directly add up their digits. The resulting sum is called s. The sheet of paper or writing surface will then be identified by (5-s) modulo 7.

In the example above, an embodiment has been described, in which each position is coded with 4 x 4 symbols, and a
25 number series with 7 bits is used. Of course, this is only an example. Positions can be coded with a greater or smaller number of symbols. The number of symbols need not be the same in both directions. The number series can be of different length and need not be binary, but may be
30 based on another base. Different number series can be used for coding in the x-direction and coding in the

18

y-direction. The symbols can have different numbers of values.

In the example above, the marking is a dot but may, of course, have a different appearance. For example, it may
5   consist of a dash which begins in the virtual raster point and extends from it to a defined position.

In the example above, the symbols within a square partial surface are used for coding a position. The partial surface may have a different shape, for example
10   hexagonal. The symbols need not be arranged in rows and columns at an angle of 90° to each other but can also be arranged in some other manner.

For the position code to be detectable, the virtual raster must be determined. This can be carried out by
15   studying the distance between different markings. The shortest distance between two markings must derive from two neighboring symbols having the value 1 and 3 so that the markings are located on the same raster line between two raster points. When such a pair of markings has been
20   detected, the associated raster points can be determined with knowledge of the distance between the raster points and the displacement of the markings from the raster points. Once two raster points have been located, addi- tional raster points can be determined by means of mea-
25   sured distances to other markings and with knowledge of the distance of the raster points from one another.

An embodiment of an apparatus for position determination, the spatial relationship of which to a surface can be determined, is shown schematically in Fig. 4. The
30   apparatus comprises a casing 11 having approximately the shape of a pen. In one short side of the casing there is an opening 12. The short side is intended to bear against

19

or be held a short distance from a surface S on which
position determination is to be carried out. In the
Figure, a normal direction $\bar{v}_z$ to the surface S and an
axis A extending through the apparatus are indicated.

5   The axis A forms an angle of inclination, or tilt, θ to
the normal direction $\bar{v}_z$.

The casing contains essentially an optics part, an
electronics part, and a power supply.

The optics part comprises at least one light emitting

10 diode 13 for illuminating the surface which is to
be imaged and a light-sensitive area sensor 14, such as
a CCD or CMOS sensor, for recording a two-dimensional
image. The apparatus may also comprise a lens system
including a schematically illustrated lens 21.

15 The power supply to the apparatus is obtained from
a battery 15 which is mounted in a separate compartment
in the casing.

The electronics part comprises image-processing means 16
for determining a position on the basis of the image

20 recorded by the sensor 14 and, more specifically,
a processor unit with a processor which is programmed to
read images from the sensor and to carry out position
determination on the basis of these images.

In this embodiment, the apparatus also comprises a pen

25 point 17, by means of which it is possible to write
ordinary pigment-based writing on the surface on which
position determination is to be carried out. The pen
point 17 is extendable and retractable so that the user
can control whether or not it is to be used. In certain

30 applications, the apparatus need not have a pen point at
all or comprise a fixed, non-retractable, pen point.

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Moreover, the device may comprise a plurality of
retractable pen points, each having, e.g., a different
color.

Moreover, the apparatus comprises buttons 18 by means of
5   which the apparatus is activated and controlled. It also
comprises a transceiver 19 for wireless transmission, for
example using IR light or radio waves, of information to
and from the apparatus. The apparatus can also comprise a
display 20 for showing positions or recorded information.

10 Applicant's International Patent application WO 98/20446
describes a device for recording text. This device can be
used for position determination if programmed in a
suitable way. If it is to be used for pigment-based
writing, it must also have a pen point.

15 The device can be divided into various physical casings,
a first casing containing components required for
capturing images of the position-coding pattern and for
transferring them to components which are located in a
second casing and carry out position determination on the
20 basis of the recorded image or images.

As mentioned above, position determination is carried out
by a processor which must therefore have software to
locate and decode the symbols in an image and
to determine positions on the basis of the codes thus
25 obtained. A person skilled in the art can, starting from
the example above, design software which carries out
position determination on the basis of an image of part
of a position-coding pattern.

Moreover, the skilled person can, on the basis of the
30 above description, design software for printing the
position-coding pattern.

In the embodiment above, the pattern is optically
readable and the sensor is therefore optical. As mention-
ed above, the pattern can be based on a parameter other
than an optical parameter. Obviously, in that case the
5   sensor must be of a type which can read the parameter in
question. Examples of such parameters are of chemical,
acoustical or electromagnetic character, e.g. resistance,
capacitance and inductance.

In the embodiment above, the raster is a rectangular
10   grid. It can also have other forms, i.e. non-rectangular.

In the embodiment above, the longest possible cyc-
lic number series is not used. Thus, there is a certain
amount of redundancy which can be used, for example, to
check the rotation of the group of symbols read.

15   With reference to Figs 5 and 6, an explanation follows of
how a grid of markings, or dots, is distorted on image
formation and how this distortion is used for calculating
the spatial orientation of an apparatus reading the
pattern or, more correctly, the relative spatial
20   orientation between the patterned surface and the reading
apparatus.

The actual calculations are performed in processing
means, such as those discussed above in connections with
figure 4, that is a processor within the device itself.
25   It is also feasible to perform the calculations in an
external processor connected to the reading device. The
software which performs the calculations is written in
accordance with the mathematical expressions to follow
and it is assumed that the person skilled in the art will
30   choose suitable tools for performing such programming.
The software may be present, or stored, in any form known
in the art, such as any volatile or non-volatile memory

22

units capable of being connected to the processor, such as a diskette or a CD-ROM, as well as propagated signals such as the stream of bits that represent Internet transmission of packets or the carrier waves that are
5   transmitted to satellites.

Fig. 6a shows schematically the pattern 601 as it appears when it is applied to a surface. The pattern is preferably in the form of such a position-coding pattern as is described above in connection with Figs 1-3. While
10   it is true that, in the patterns used as examples previously, a plurality of the markings are displaced in relation to an orthogonal raster, these displacements are assumed to be relatively small and thus of minor significance in this embodiment. The displacements may also,
15   however, be part of a larger plurality of predetermined vectors which in that case are also incorporated in the calculations.

In the discussion to follow, it is assumed that the sensor (i.e. sensor 14 in figure 4) is arranged such that
20   its normal direction is parallel with the direction of extension of the device. The person skilled in the art may adapt the calculations to allow for other relations between the sensor normal direction and the device.

The points in the square grid, as illustrated in Fig. 6a,
25   are imaged through a lens 503, e.g. lens 21 in figure 4, on the surface 502 of a sensor located in the reading apparatus. The pattern 602 on the sensor surface is, as shown in Fig. 6b, distorted because the relative spatial orientation between the reading apparatus and the
30   patterned surface is not orthogonal.

23

In this case, the pattern is characterized in that inherent stretches are described by the predetermined two-dimensional vectors

$$\left\{a : a = k_{xi}\hat{x} + k_{yi}\hat{y}\right\}$$

where k_{xi}, k_{yi} are integers and $\hat{x}, \hat{y}$ are two-dimensional base vectors. This pattern is to be compared with the distorted image on the sensor surface.

10   In order to model the image formation through the lens system, a coordinate system is selected which is fixed in relation to the sensor and the lens and in which the lens is located at the origin. It is assumed that all the light rays from the surface to the sensor pass

15   unrefracted through the origin. The degrees of freedom of the model are the distance to and the orientation of the patterned surface.

A point P_0 on the sensor is selected. The stretch from P_0 to the lens is defined by the vector $\bar{v}_0$. In the same

20   manner, a vector $\bar{v}_i$ belonging to the point P_i is defined. Given this model of image formation, a vector $\bar{v}_k$ from the origin to the point P_k in the image on the sensor will be parallel to the vector $\bar{v}'_k$ from the origin to the corresponding point P'_k on the patterned surface:

25

$$\bar{v}'_k = c_k v_k$$

Two spatial vectors $\hat{v}_x$ and $\hat{v}_y$ can be introduced, which lie in the plane of the patterned surface and constitute base vectors for the grid as it is rotated in space. By

30   using the predetermined vectors, the vector from the

24

point P'_0 in the pattern on the surface to any other point P'_i is, expressed in $\hat{v}_x$ and $\hat{v}_y$, given by:

$$v'_i - v'_0 = k_{xi}\hat{v}_x + k_{yi}\hat{v}_y$$

5   where the integers k_{xi}, k_{yi} describe the integer position of a point in the grid relative to P'_0. We can thus describe a relationship according to Fig. 5:

$$c_o\bar{v}_o + k_{xi}\hat{v}_x + k_{yi}\hat{v}_y = c_i\bar{v}_i$$

10   By introducing the vectors

$$\bar{v}_x \equiv \frac{1}{c_0}\hat{v}_x, \quad \bar{v}_y \equiv \frac{1}{c_0}\hat{v}_y$$

the following is obtained:

15          $$\bar{v}_o + k_{xi}\bar{v}_x + k_{yi}\bar{v}_y = \frac{c_i}{c_0}\bar{v}_i$$

An equation for each dimension is then:

$$\begin{cases} v_{0x} + k_{xi}v_{xx} + k_{yi}v_{yx} = \dfrac{c_i}{c_0}v_{ix} \\[2mm] v_{0y} + k_{xi}v_{xy} + k_{yi}v_{yy} = \dfrac{c_i}{c_0}v_{iy} \\[2mm] v_{0z} + k_{xi}v_{xz} + k_{yi}v_{yz} = \dfrac{c_i}{c_0}v_{iz} \end{cases}$$

25

Division results in identical right-hand parts:

$$
\begin{cases}
\dfrac{v_{0x}}{v_{ix}} + \dfrac{k_{xi}}{v_{ix}} v_{xx} + \dfrac{k_{yi}}{v_{ix}} v_{yx} = \dfrac{c_i}{c_0} \\[2ex]
\dfrac{v_{0y}}{v_{iy}} + \dfrac{k_{xi}}{v_{iy}} v_{xy} + \dfrac{k_{yi}}{v_{iy}} v_{yy} = \dfrac{c_i}{c_0} \\[2ex]
\dfrac{v_{0z}}{v_{iz}} + \dfrac{k_{xi}}{v_{iz}} v_{xz} + \dfrac{k_{yi}}{v_{iz}} v_{yz} = \dfrac{c_i}{c_0}
\end{cases}
$$

For each point P_i, there is therefore an equation system of the type:

5      $a_{xi} + b_{xi} v_{xx} + c_{xi} v_{yx} = a_{yi} + b_{yi} v_{xy} + c_{yi} v_{yy} = a_{zi} + b_{zi} v_{xz} + c_{zi} v_{yz}$ (1)

where the unknowns are:

$$(v_{xx} \quad v_{xy} \quad v_{xz}) \equiv \bar{v}_x \quad \text{and} \quad (v_{yx} \quad v_{yy} \quad v_{yz}) \equiv \bar{v}_y$$

If the number of points is greater than five, there is a redundant equation system in, for example, v_{xx}, v_{xy}, v_{yx} and v_{yy}:

$$
\begin{pmatrix}
b_{x1} & -b_{y1} & c_{x1} & -c_{y1} \\
b_{x2} & -b_{y2} & c_{x2} & -c_{y2} \\
\cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot \\
\cdot & \cdot & \cdot & \cdot \\
b_{xn} & -b_{yn} & c_{xn} & -c_{yn}
\end{pmatrix}
\begin{pmatrix}
v_{xx} \\
v_{xy} \\
v_{yx} \\
v_{yy}
\end{pmatrix}
=
\begin{pmatrix}
a_{y1} - a_{x1} \\
a_{y2} - a_{x2} \\
\cdot \\
\cdot \\
\cdot \\
a_{yn} - a_{xn}
\end{pmatrix}
$$

10

The least square method gives v_{xx}, v_{xy}, v_{yx} and v_{yy}. v_{xx} and v_{xy} are inserted into equation (1) and a similar equation system is obtained for v_{xz} and v_{yz} which is also solved by means of the least square method.

26

The direction of the vectors $\overline{v}_x$ and $\overline{v}_y$ is thus known, and in this way the spatial orientation of the pattern read has been determined.

The vectors $\overline{v}_x$ and $\overline{v}_y$ obtained then give a normal vector

5   to the patterned surface through the cross product $\overline{v}_z = \overline{v}_x \times \overline{v}_y$. The angle θ between the normal vector $\overline{v}_z$ and the z axis, which is fixed in the apparatus, is given by

$$\cos\theta = \frac{v_{zz}}{|\overline{v}_z|}$$

Usually, as is known in the art, the orientation of a

10 device such as a pen with respect to the pattern on the surface can be expressed using three numbers: rotation, tilt and skew. The skew is defined as the angle of rotation of the pen around its rotational axis. The tilt angle is the angle the pen extends with respect to a

15 normal vector to the surface and the rotation is the angle of rotation of the pen with respect to the normal vector. A zero tilt implies that the rotation is equal to the skew. These angles are illustrated in figure 4, where the normal vector to the surface is denoted N, rotation

20 is denoted R, the tilt is denoted θ and the skew is denoted SK. Note that in figure 4, the axis A of the device illustrates a coinciding optical axis and axis of rotation of the device.

In order to calculate rotation, tilt and skew, we begin

25 by noting from above that

$$\overline{v}_x \equiv \frac{1}{c_0}\hat{v}_x \quad \text{and} \quad \overline{v}_y \equiv \frac{1}{c_0}\hat{v}_y$$

from which equations, c_0 can be calculated.

27

A vector $\bar{V}'_0$ extending from the origin to the surface on which the pattern is located, parallel with the vector $\bar{v}_0$ extending from P_0 to the origin, is given by

$$\bar{V}'_0 = c_0 \bar{v}_0$$

5   We also know from above that the normal vector to the surface, extending away from the pen, is given by

$$\hat{v}_n = \hat{v}_x \times \hat{v}_y$$

Now an equation for the plane of the surface can be calculated. The distance from the origin to the surface
10 is given by

$$h = \frac{\bar{v}'_0 \cdot \hat{v}_n}{|\hat{v}_n|}$$

For each vector $\bar{v}_p = (x_p, y_p, z_p)$ from the origin to the plane of the surface the expression

$$h = \frac{\bar{v}_p \cdot \hat{v}_n}{|\hat{v}_n|}$$

15 holds, which gives an equation for the plane of the surface:

$$P_x x_p + P_y y_p + P_z z_p + P_0 = 0$$

The axis of the pen is assumed to be parallel with the z-axis. Hence, a vector extending from the origin to the
20 surface, parallel with the axis of the pen can be calculated by inserting $x_p=0$ and $y_p=0$ in the equation for the plane of the surface:

$$\bar{v}_{0p} = (0, 0, -P_0 / P_z)$$

The angle between the normal vector and $\bar{v}_{0p}$ gives the
25 tilt:

28

$$tilt = \cos^{-1}\left(\frac{\bar{v}_{0p} \cdot \hat{v}_n}{|\bar{v}_{0p}| \cdot |\hat{v}_n|}\right)$$

If the tilt is non-zero, the skew can be calculated. The projection of the normal vector onto the xy-plane gives:

$$\hat{v}_{np} = (v_{nx}, v_{ny}, 0)$$

5   Then the skew is given by the angular deviation from the y-axis:

$$\pm skew = \cos^{-1}\left(\frac{\hat{v}_{np} \cdot (0,1,0)}{|\hat{v}_{np}|}\right)$$

where the skew is positive when v_{nx} is positive and negative otherwise.

10   The projection of the axis of the pen onto the plane of the surface is now obtained by:

$$\bar{p}_v = \left(proj_x, proj_y\right)$$

where

$$proj_x = \bar{v}_{0p} \cdot \hat{v}_x \quad \text{and} \quad proj_y = \bar{v}_{0p} \cdot \hat{v}_y$$

15   The angle between this vector and the vectors of the pattern gives the rotation:

$$rot = \pm\cos^{-1}\left(\frac{proj_x}{|\bar{p}_v|}\right)$$

and, if the tilt is zero, we have:

$$rot = \pm\cos^{-1}\left(\frac{-v_{xx}}{|\hat{v}_x|}\right)$$

20   where a positive y-coordinate implies a positive rotation.

29

The position of the tip of the pen can be calculated by considering the fact that, when the pen changes orientation, during writing for example, the equation for the plane of the surface will change. By considering such

5   a changing equation for the plane of the surface as a sequence of different planes in which the tip of the pen is located, the position of the tip can simply be found by noting that only one point will be common to all planes: the point of the tip of the pen. This calculation

10   can be performed when there are available at least three different equations for the plane of the surface.

A plane is defined by an equation, as indicated above, by it's coefficients. For a plane i, we have:

$$\left(P_{xi}, P_{yi}, P_{zi}, P_{0i}\right)$$

15   The position of the tip of the pen is given by a system of equations:

$$\begin{cases} P_{x0}x + P_{y0}y + P_{z0}z + P_{00} = 0 \\ P_{x1}x + P_{y1}y + P_{z1}z + P_{01} = 0 \\ \quad\quad\quad \vdots \\ P_{xk}x + P_{yk}y + P_{zk}z + P_{0k} = 0 \end{cases}$$

which can be solved in accordance with any procedure known in the art, yielding the xyz-coordinates, a

20   distance vector, for the tip of the pen.

The exact position of the physical tip of the pen may then be utilized to find the exact displacement between the tip and the position calculated from the position coding pattern, i.e. the center of the images obtained.

25   Such a displacement is inherent and, in essence, unavoidable since the optical axis of the lens system of the pen does not coincide with the writing pen. The displacement is not necessarily known in advance due to

mechanical inaccuracies when assembling the pen as well as inaccuracies occurring when performing refill-replacement-actions in the case the pen is equipped with a replaceable refill defining the writing tip. In a pen

5 equipped with multiple tips, for example of different colors, the location of the tip with respect to the sensor will vary for each color. Such variations in tip location can be determined , and accounted for, by way of the present invention.

10 The calculated displacement is preferably used to synchronize the physical track made by the pen and the digitally recorded track as determined by the center of the images. This is advantageous in that it obviates the need to mechanically measure and calibrate the spatial

15 relation between the tip of the pen and the optical system.

CLAIMS

1. An apparatus for determining a three-dimensional spatial relationship between a surface (S) provided with a predetermined pattern (601) and the apparatus,

5   comprising:

- means for imaging a part of the pattern,
- means for comparing the imaged part (602) of the pattern with the predetermined pattern, at least one reference measurement being obtained, which depends on

10   the orientation $(\overline{v}_x, \overline{v}_y, \overline{v}_z)$ of the surface,

- means for determining, by means of the reference measurement, the spatial relationship expressed in at least the parameters which define the orientation of the surface.

15   2. An apparatus according to claim 1, wherein the means for comparison comprise means for comparing between a number of directed stretches in the image and predetermined vectors which follow from the predetermined pattern.

20   3. An apparatus according to claim 2, comprising means for adaptation according to the least square method.

4. An apparatus according to any one of the preceding claims, wherein the spatial relationship comprises a distance vector between the apparatus and the surface

25   from which the pattern has been imaged.

5. An apparatus according to any one of the preceding claims, wherein the spatial relationship at least comprises an angle between an axis extending through the apparatus and the surface from which the pattern has been

30   imaged.

32

6. An apparatus according to any one of claims 1-5, wherein the means for comparison comprise means for determining a set of parameters which define a vector which, in relation to a plane extending through the appa-

5   ratus, unambiguously determines an inclination for the surface from which the pattern has been imaged.

7. An apparatus according to any one of claims 1-5, wherein the means for comparison comprise means for determining a set of parameters which define a vector

10   which unambiguously determines a normal vector for the surface from which the pattern has been imaged.

8. An apparatus according to any one of claims 1-5, wherein the means for comparison comprise means for determining at least one parameter which unambiguously

15   defines an angular orientation for the imaged pattern about a normal vector for the surface from which the pattern has been imaged.

9. An apparatus according to any one of claims 1-8, wherein the means for comparison comprise means for

20   determining at least one parameter which unambiguously defines at least one of rotation, tilt and skew of the apparatus.

10. An apparatus according to any one of claims 1-5, wherein the imaging means comprise means for one-dimen-

25   sional pattern imaging.

11. An apparatus according to any one of claims 1-9, wherein the imaging means comprise means for two-dimen-sional pattern imaging.

12. An apparatus according to any one of claims 1-11,

30   wherein the apparatus is hand-held.

33

13. An apparatus according to any one of claims 1-12, wherein the apparatus has means (19) for wireless transmission of information.

14. An apparatus according to any one of claims 1-13,
5 wherein the apparatus is in the general form of a pen and comprises means for determining the position of a tip of the pen.

15. An apparatus for position determination, comprising a sensor (14) for producing an image of one partial surface
10 of a plurality of partial surfaces on a surface, which is provided with a position-coding pattern, and image-processing means (16), which are arranged to

- locate a predetermined plurality of symbols in the image, each symbol comprising a raster point (5) and at
15 least one marking (6), the raster point forming part of a raster which extends over the surface and the value of each symbol being indicated by the position of said marking in relation to a raster point,

- determine the value of each of said predetermined
20 plurality of symbols,

- separate the position-coding pattern in the image into a first position code for a first coordinate for the partial surface and a second position code for a second coordinate for the partial surface by translating
25 the value of each symbol into at least one first digit for the first position code and at least one second digit for the second position code,

- calculate the first coordinate by means of the first position code and the second coordinate by means
30 of the second position code,

- compare the imaged part of the pattern (602) with the predetermined pattern (601), at least one reference

34

measurement being obtained, which depends on the orientation $(\bar{v}_x, \bar{v}_y, \bar{v}_z)$ of the surface,

- determine, by means of the reference measurement, a three-dimensional spatial relationship between the
5   surface and the apparatus expressed in at least the parameters which define the orientation of the surface,

- calculate a third coordinate, use being made of the measurement of the spatial relationship.

16. An apparatus according to claim 15, wherein the
10   image-processing means are also arranged to carry out a comparison between a number of directed stretches in the image and predetermined vectors which follow from the predetermined pattern.

17. An apparatus according to claim 16, wherein the
15   image-processing means are also arranged to carry out adaptation according to the least square method.

18. An apparatus according to any one of claims 15-17, wherein the spatial relationship comprises a distance vector between the apparatus and the partial surface from
20   which the position-coding pattern has been imaged.

19. An apparatus according to any one of claims 15-18, wherein the spatial relationship at least comprises an angle between an axis extending through the apparatus and the partial surface from which the position-coding
25   pattern has been imaged.

20. An apparatus according to any one of claims 15-19, wherein the means for comparison comprise means for determining a set of parameters which define a vector which, in relation to a plane extending through the appa-
30   ratus, unambiguously determines an inclination for the surface from which the pattern has been imaged.

21. An apparatus according to any one of claims 15-19, wherein the image-processing means are also arranged to determine a set of parameters which define a vector which unambiguously determines a normal vector for the surface
5   from which the pattern has been imaged.

22. An apparatus according to any one of claims 15-19, wherein the image-processing means are also arranged to determine at least one parameter which unambiguously defines an angular orientation for the imaged pattern
10   about a normal vector for the partial surface from which the pattern has been imaged.

23. An apparatus according to any one of claims 15-22, wherein the means for comparison comprise means for determining at least one parameter which unambiguously
15   defines at least one of rotation, tilt and skew of the apparatus.

24. An apparatus according to any one of claims 15-19, wherein the image-processing means are also arranged for one-dimensional pattern imaging.

20   25. An apparatus according to any one of claims 15-22, wherein the image-processing means are also arranged for two-dimensional pattern imaging.

26. An apparatus according to any one of claims 15-25, wherein the apparatus is hand-held.

25   27. An apparatus according to any one of claims 15-26, wherein the apparatus has means (19) for wire-less transmission of information.

28. An apparatus according to any one of claims 15-27, wherein the apparatus is in the general form of a pen and
30   comprises means for determining the position of a tip of the pen.

29. A method for determining a three-dimensional spatial
relationship between a surface (S) provided with a
predetermined pattern (601) and an apparatus capable of

5   at least imaging the surface, comprising:
        - imaging a part of the pattern,
        - comparing the imaged part (602) of the pattern
with the predetermined pattern, at least one reference
measurement being obtained, which depends on the orien-

10 tation $(\bar{v}_x, \bar{v}_y, \bar{v}_z)$ of the surface,

        - determining, by means of the reference measure-
ment, the spatial relationship expressed in at least the
parameters which define the orientation of the surface.

30. A method according to claim 29, wherein the

15 comparison is carried out between a number of directed
stretches in the image and predetermined vectors which
follow from the predetermined pattern.

31. A method according to claim 30, wherein the
adaptation is carried out according to the least square

20 method.

32. A method according to any one of claims 29-31,
wherein the spatial relationship comprises a distance
vector between the apparatus and the surface from which
the pattern has been imaged.

25 33. A method according to any one of claims 29-32,
wherein the spatial relationship at least comprises an
angle between an axis extending through the apparatus and
the surface from which the pattern has been imaged.

34. A method according to any one of claims 29-33,

30 wherein the comparison comprises determining a set of
parameters which define a vector which, in relation to

37

a plane extending through the apparatus, unambiguously determines an inclination for the surface from which the pattern has been imaged.

35. A method according to any one of claims 29-33, wherein the comparison comprises determining a set of parameters which define a vector which unambiguously determines a normal vector for the surface from which the pattern has been imaged.

36. A method according to any one of claims 29-33, wherein the comparison comprises determining at least one parameter which unambiguously defines an angular orientation for the imaged pattern about a normal vector for the surface from which the pattern has been imaged.

37. A method according to any one of claims 29-36, wherein the comparison comprise determining at least one parameter which unambiguously defines at least one of rotation, tilt and skew of the apparatus.

38. A method according to any one of claims 29-33, wherein the image formation comprises one-dimensional pattern imaging.

39. A method according to any one of claims 29-36, wherein the image formation comprises two-dimensional pattern imaging.

40. A method according to any one of claims 29-37, wherein the apparatus is in the general form of a pen and the method comprises determining the position of a tip of the pen.

41. A computer program which is stored in a computer-readable memory medium and which comprises instructions for making a computer carry out the method according to any one of claims 29-40.

38

42. A method for position determination, comprising
producing an image of one partial surface of a plurality
of partial surfaces on a surface, which is provided with
a position-coding pattern, and carrying out image-
5   processing, which comprises
        - locating a predetermined plurality of symbols in
the image, each symbol comprising a raster point (5) and
at least one marking (6), the raster point forming part
of a raster which extends over the surface and the value
10   of each symbol being indicated by the position of said
marking in relation to a raster point,
        - determining the value of each of said predetermin-
ed plurality of symbols,
        - separating the position-coding pattern in the
15   image into a first position code for a first coordinate
for the partial surface and a second position code for a
second coordinate for the partial surface by translating
the value of each symbol into at least one first digit
for the first position code and at least one second digit
20   for the second position code,
        - calculating the first coordinate by means of the
first position code and the second coordinate by means of
the second position code,
        - comparing the imaged part of the pattern (602)
25   with the predetermined pattern (601), at least one refe-
rence measurement being obtained, which depends on the
orientation $(\bar{v}_x, \bar{v}_y, \bar{v}_z)$ of the surface,
        - determining, by means of the reference measure-
ment, a three-dimensional spatial relationship between
30   the surface and the apparatus expressed in at least the
parameters which define the orientation of the surface,
        - calculating a third coordinate, use being made of
the spatial relationship.

43. A method according to claim 42, wherein the comparison is carried out between a number of directed stretches in the image and predetermined vectors which follow from the predetermined pattern.

5   44. A method according to claim 43, wherein the adaptation is carried out according to the least square method.

45. A method according to any one of claims 42-44, wherein the spatial relationship comprises a distance

10   vector between the apparatus and the partial surface from which the position-coding pattern has been imaged.

46. A method according to any one of claims 42-45, wherein the spatial relationship at least comprises an angle between an axis extending through the apparatus and

15   the partial surface from which the position-coding pattern has been imaged.

47. A method according to any one of claims 42-47, comprising determining a set of parameters which define a vector which, in relation to a plane extending through

20   the apparatus, unambiguously determines an inclination for the surface from which the pattern has been imaged.

48. A method according to any one of claims 42-46, comprising determining a set of parameters which define a vector which unambiguously determines a normal vector for

25   the surface from which the pattern has been imaged.

49. A method according to any one of claims 42-46, comprising determining at least one parameter which unambiguously defines an angular orientation for the imaged pattern about a normal vector for the partial surface

30   from which the pattern has been imaged.

50. A method according to any one of claims 42-49, wherein the comparison comprise determining at least one parameter which unambiguously defines at least one of rotation, tilt and skew of the apparatus.

5   51. A method according to any one of claims 42-46, wherein the image formation comprises one-dimensional pattern imaging.

52. A method according to any one of claims 42-49, wherein the image formation comprises two-dimensional
10   pattern imaging.

53. A method according to any one of claims 42-52, wherein the apparatus is in the general form of a pen and the method comprises determining the position of a tip of the pen.

15   54. A computer program which is stored in a computer-readable memory medium and which comprises instructions for making a computer carry out the method according to any one of claims 42-53.

55. Use of distortion in an image of a patterned surface
20   for calculation of the relative spatial orientation between the surface and an apparatus capturing said image.

56. Use according to claim 55, wherein said relative spatial orientation includes a rotation and/or a tilt
25   and/or a skewing and/or a distance between the surface and the apparatus.

57. Use according to claim 55 or 56, wherein said apparatus is a digital pen.
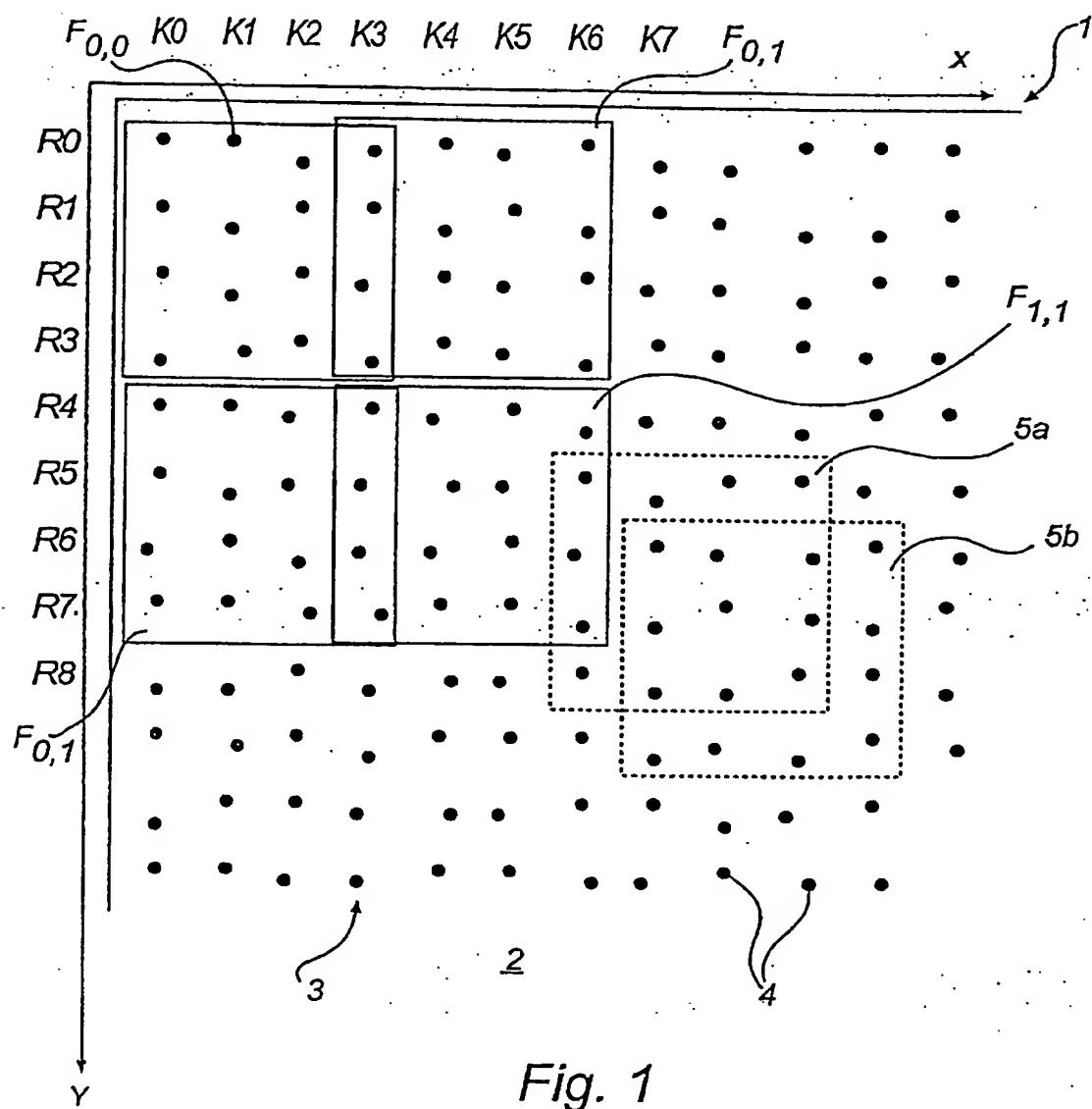
Fig. 1
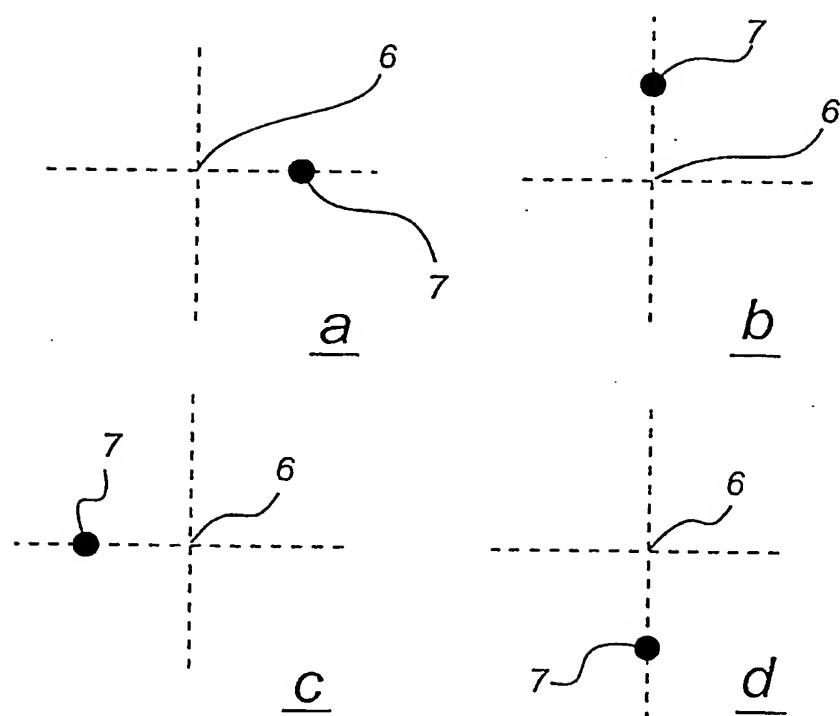
Fig. 2
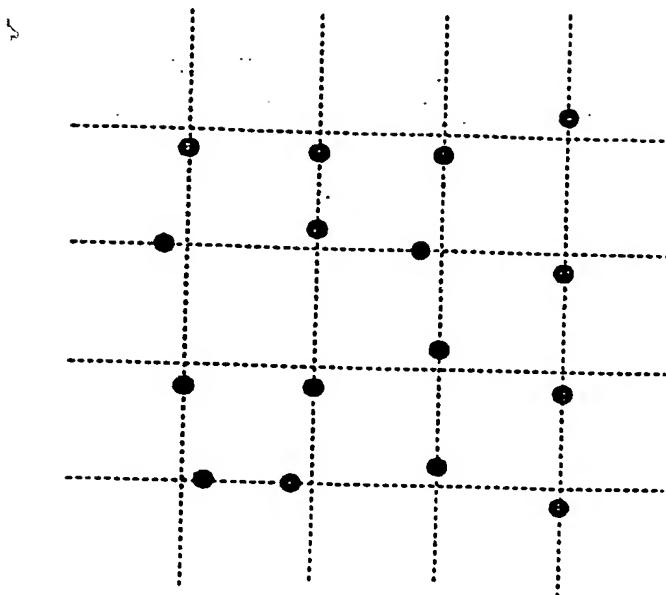
Fig. 3
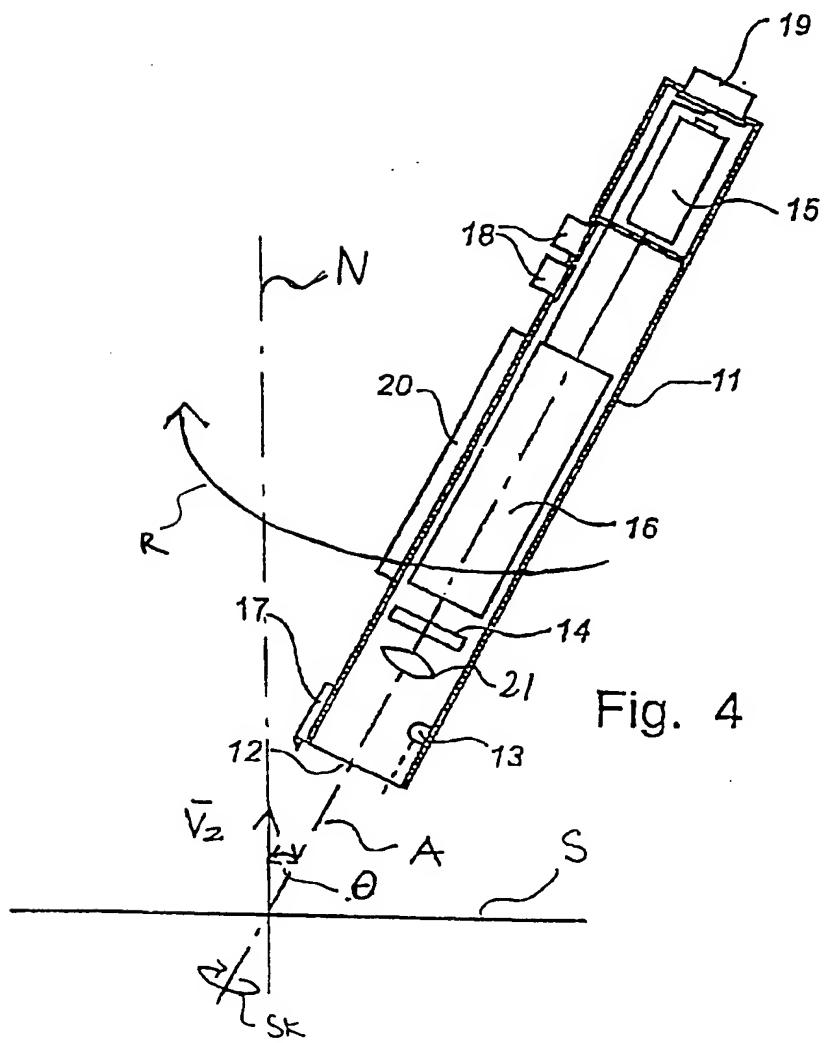
Fig. 4
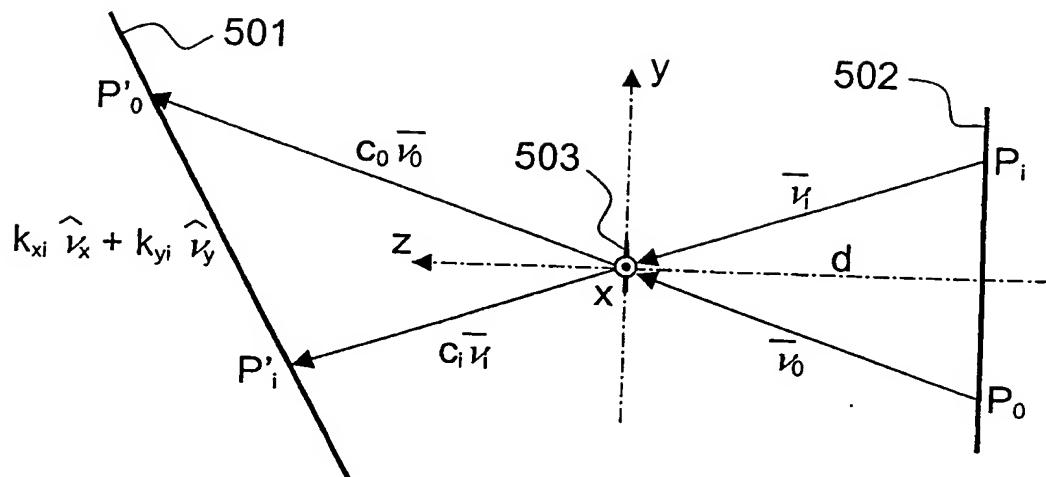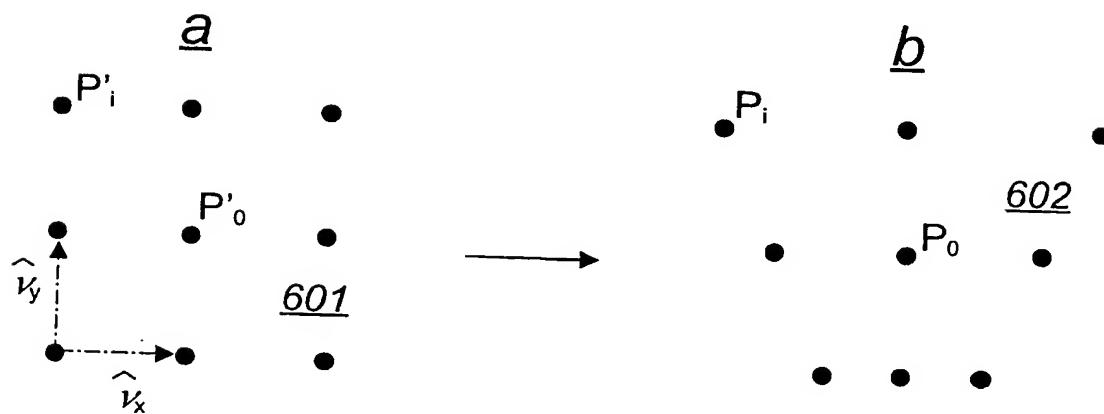
501

P'_0

$c_0 \overline{\nu_0}$

503

502

$\overline{\nu_i}$

P_i

$k_{xi}\, \widehat{\nu}_x + k_{yi}\, \widehat{\nu}_y$

y

z

d

x

$c_i \overline{\nu_i}$

P'_i

$\overline{\nu_0}$

P_0

Fig. 5

$\underline{a}$

$\underline{b}$

$\bullet P'_i$

$\bullet$

$\bullet$

$\bullet P_i$

$\bullet$

$\bullet$

P'_0

$\bullet$

$\bullet$

$\underline{602}$

$\widehat{\nu}_y$

$\bullet$

601

$\bullet P_0$

$\bullet$

$\widehat{\nu}_x$

$\bullet$

$\bullet$

$\bullet$

$\bullet$

$\bullet$

Fig. 6

1

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: G06K 11/18, G06F 3/033
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC7: G06F, G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI-DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5101096 A (S.OHYAMA ET AL), 31 March 1992 (31.03.92), column 1, line 44 - column 2, line 19, figure 2, abstract	1-11,29-39, 41,55-56
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A	WO 9410652 A1 (S.M.MAK), 11 May 1994 (11.05.94), page 4, line 20 - page 9, line 21, abstract	1-57
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A	US 5652412 A (M.LAZZOUNI ET AL), 29 July 1997 (29.07.97), column 2, line 38 - column 3, line 34, figure 7	1-57
	--	

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 May 2001	19 -06- 2001
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INTERNATIONAL SEARCH REPORT

International application No.

PCT/SE 01/00610

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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				FI	803247 A	24/04/81
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				DE	3014350 A,C	22/10/81